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4. EUROPEAN LOW ENERGY BUILDING

4.1. Low Energy Building and its Meaning in 2022

The concept of low energy buildings is changing continuously with frequent changes to regulations, requirements and law acts to comply with. Actual energy consumption factors are significantly lower that it could be predicted several years ago, especially in case of primary energy facts that take into account renewable energy sources. Anyway, due to external conditions like local climate parameters or availability of renewable energy sources (RES), national concepts of low energy buildings or nZEBs differ.

Consequently, every few years, new national regulations regarding heat transfer coefficients of external barriers like roofs, windows or walls are changed and the values are reduced. In countries located in northern and eastern Europe, like Poland, Lithuania or Latvia, it is crucial to ensure low heat losses in winter, because of significantly low external temperatures, hence high difference between indoor and outdoor temperature. According to guide (Passivhaus Institut, Passive House Component Guidelines) Latvia and Lithuania are defined as cold, while Poland cold/cool temperate. Current requirements for the maximum U values (heat transfer coefficients) for new buildings are shown in Table 4.1.

TABLE 4.1. U values in Poland, Lithuania and Latvia (Source: own elaboration based on Announcement of the Minister of Investment and Development of 8 April 2019; Muranoa et al., 2017; WEB–1; WEB–2)

	Country		
Type of barrier [$W/m^2 K$]	Poland	Lithuania	Latvia
External wall [$W/m^2 K$]	0.20	0.12k	0.18k’
Roof [$W/m^2 K$]	0.15	0.10k	0.15k’
Window [$W/m^2 K$]	0.90	1.00k	1.30k’

* $k = 20/(\theta i - \theta e)$,– temperature correction factor, where θi = indoor air temperature in degrees Celsius, θe = outdoor air temperature or design temperature of adjacent space in degrees Celsius. Temperature of unheated spaces is determined separately. If indoor air temperature θi = 20°C and outdoor air θe = 0°C, then k = 1

** $k' = 19//(\theta i - \theta e)$, depending on climate zones, k’ for residential buildings is from 0.95 (Liepāja) to 1.09 (Alūksne)

In countries located in southern Europe, like Spain or Italy, the limit is significantly higher (Table 4.2). According to guide (Passivhaus Institut, Passive House Component Guidelines) Italy is cool temperate/warm temperature/warm depending on its part, while Spain as warm temperature/warm.

TABLE 4.2. U values in Spain and Italy (Source: own elaboration based on Borrallo-Jiménez et al., 2022; Bac et al., 2022; Ministerio de Fomento, 2019; Berardi et al., 2018; Muranoa et al., 2017)

	Country	
Type of barrier [W/m^2 K]	Spain	Italy
External wall [W/m^2 K]	0.56	0.26-0.43
Roof [W/m^2 K]	0.44	0.25-0.35
Window [W/m^2 K]	2.30	1.40-3.00

National requirements differ significantly, not only between themselves but also in comparison with other local and regional regulations. On the one hand in some cases, for example in Poland, U limits are clear and constant for the whole country, while in other cases they depend on a country zone. Moreover, as shown by Borrallo-Jimenez et al. (Borrallo-Jiménez et al., 2022), the regulations of the Spanish Technical Building Code (Ministry of Public Works and Transport, Royal Decree, 2019) consider several climate classifications, adjusting their requirements to the climatic zone of the new building, whereas the Passive House (PH) rules (Muranoa et al., 2017) for warm climates take into account two climate classifications for Spain. Moreover, requirements related to the usage of RESs and primary energy factors come and go. EPDB 2010 recast (European Parliament, Council of the European Union, 2010) promotes the usage of RES, as well as cost-optimal technologies that guarantee a healthy and comfortable environment.

In case of nZEBs, the limiting and optimizing values of U values are more complicated, than for PHs or low energy buildings, as they cannot be easily established. It is important to improve the energy performance of buildings not only by reduction of heat transfer coefficients of external barriers. Thus, it is crucial to combine low energy HVAC, DHW and lighting systems and smart technologies with renewable energy sources (D'Agostino et al., 2021).

Similar approach to achieving the of nZEBs level was presented by Firlag and Piasecki (Firlag & Piasecki, 2018). Fabrizio (Fabrizio, 2020) noted that the design of a ZEB required a holistic approach and its target could be reached with the best combination of envelope, systems and energy sources, under technical and financial constraints that change in space and time.

In Poland, Bac (Bac, 2022) studied the level of awareness of Polish architects regarding the possibilities of improving the energy efficiency of buildings, the use of energy performance, and the achievement of the nZEB standard. Martinez-de-Alegria et al. (Martinez-de-Alegria et al., 2021) analyzed a set of certified PH buildings and found that they met requirements for nearly zero-energy buildings under the Spanish certification system.

D'Agostino et al. (D'Agostino et al., 2021) reported examples of nZEBs best practices from many countries like Poland, France, Germany, Bulgaria, Croa-tia, Austria etc. They set the lowest value of external wall U coefficient at the level of 0.08 W/(m^{2}K), while the highest U = 0.4 W/(m^{2}K) was found in Croa-tia. In case of windows, the values were between 0.27 (Estonia) and 1.76 W/(m^{2}K) (France). The heat transfer coefficient for roofs differed from 0.07 (Poland) to 0.26 W/(m^{2}K) (Bulgaria).

4.2. Examples of low Energy Buildings Located in Several EU Countries

4.2.1. Description of the Building With Low Energy Consumption

The building of Laboratory of Energy Efficient Architecture and Renewable Energy (LEEARE) was chosen as a model facility that is characterized by low energy consumption. It was established in August 2015 and is located at the Faculty of Architecture of the Bialystok University of Technology (BUT). The author of the idea and the conceptual design was D.Arch. Adam Turecki, and the design was prepared by architect Andrzej Rydzewski. LEEARE was made as part of a multi-stage project financed 80% by the European Union and 20% by BUT. The title of this project was "Study of the effectiveness of active and passive methods to improve the energy efficiency infrastructure located at BUT and supported by renewable energy sources". More information on this subject was presented in publication (Żukowski, 2017). This laboratory building was designed to be used as a typical single-family building (Fig. 4.1). It has a basement and two overground storeys. Net conditioned building area, denoted in further calculations as A_{net}, is 177.47 m^2.

FIG. 4.1. Laboratory of Energy Efficient Architecture and Renewable Energy – south facade (Source: photo by M. Żukowski)

The facility contains many modern solutions and technologies that use renewable energy sources. These are thermal solar collectors (TSC) for domestic hot water (DHW) heating, photovoltaic (PV) panels and wind turbines. The source of energy is a ground-water heat pump. A ventilated Double Skin Facade (DSF) is a passive element used to increase the heat gain from solar radiation. Building partitions are characterized by very high thermal insulation. Their characteristics are presented in Table 4.3.

TABLE 4.3. U values [W/m^2 K] of selected partitions (Source: own elaboration)

Type of partition	U value [W/m^2 K]
External wall	0.113
Wall below grade	0.175
Ground floor	0.136
Roof	0.080
External window	0.780
Internal window	1.512

4.2.2. Model of the Building and HVAC Systems

In order to determine the energy performance of the building studied in this chapter, its model was developed. The DesignBuilder software was used for modelling the body of the laboratory building as well as heating and ventilation systems. Figure 4.2 shows the layout of the test object. A render view without the basement but with two solar thermal collectors and a photovoltaic array is shown in Figure 4.3. The shading of the building is set for April 15 at 11 am.

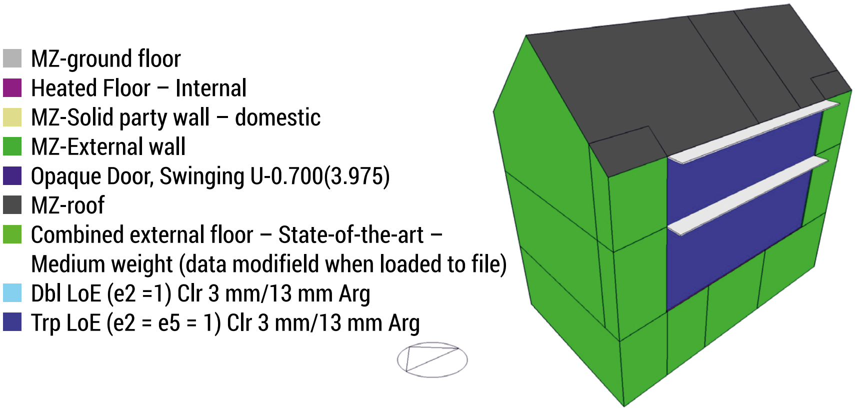

FIG. 4.2. Model of the building body including the type of partitions (Source: own elaboration)

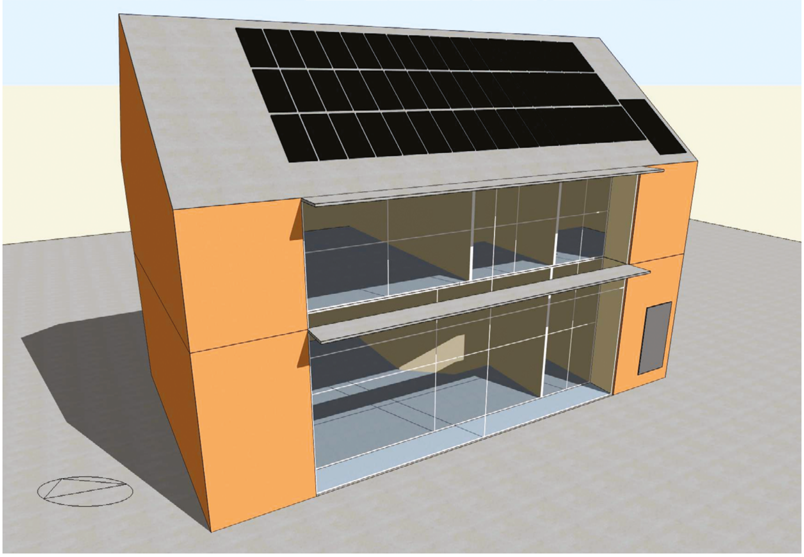

FIG. 4.3. View of the laboratory building with solar collectors on the roof and one on the facade (Source: own elaboration)

The energy source is a glycol-water heat pump with a ground heat exchanger, which consists of 4 vertical probes 100 m deep (Fig. 4.4). The conditioned spaces are heated by means of underfloor heating. The building is equipped with a mechanical ventilation with a heat recovery unit from the exhaust air. The air from the toilets is exhausted directly to the outside. The production of domestic hot water (DHW) is supported by two solar collectors with a total area of 3.97 m^2 (Fig. 4.5). One is on the roof and the other on the south facade. The heat is stored in a water tank with a capacity of 750 liters. The demand for DHW is estimated at 99.79 m^3. The photovoltaic system consists of 48 PV modules BP585 with dimensions of 1209 mm by 537 mm and a maximum power of 85 W.

In order to demonstrate the influence of climatic parameters on the building characteristics, the following five locations in Europe were selected:

- Bialystok (Poland),
- Kaunas (Lithuania),
- Helsinki (Finland),
- Bologna (Italy),
- Cordoba (Spain).

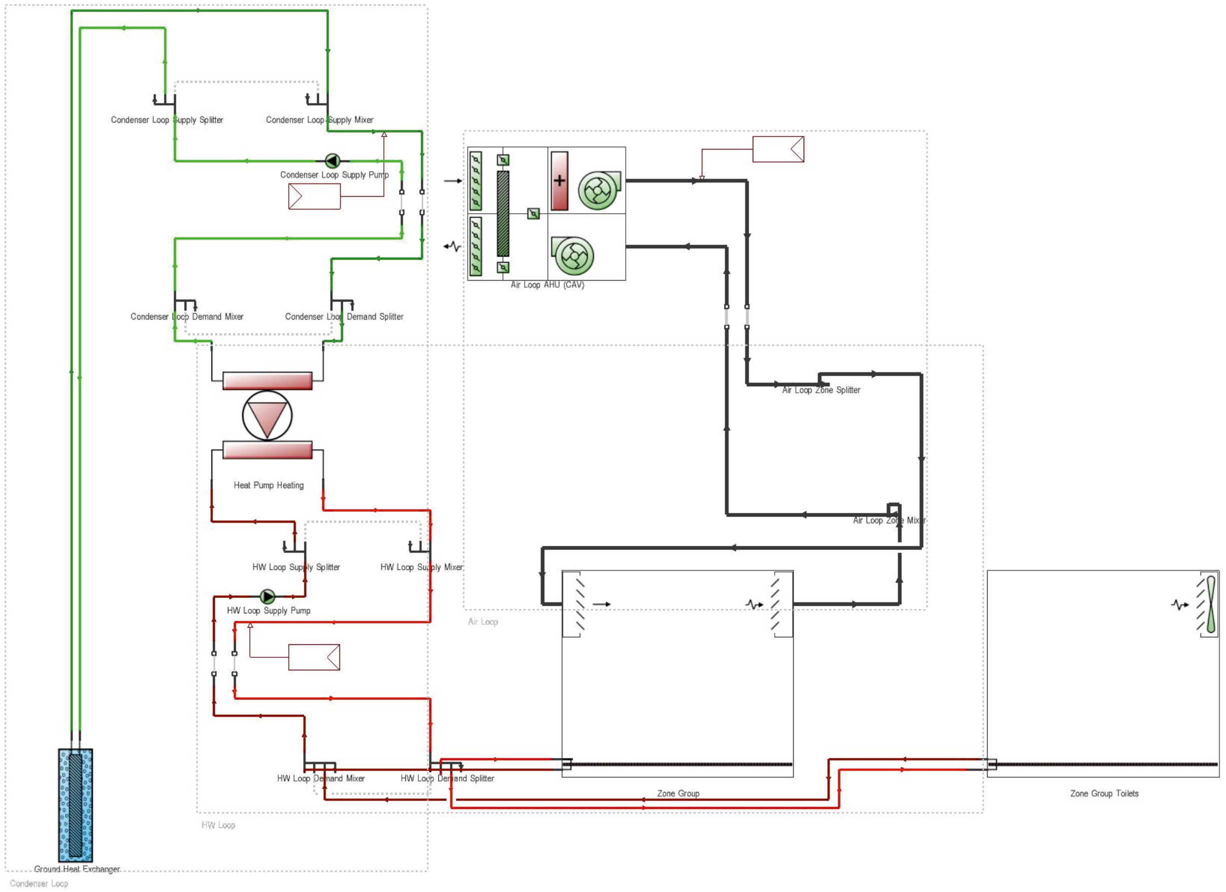

FIG. 4.4. Scheme of the heating and ventilation system (Source: own elaboration)

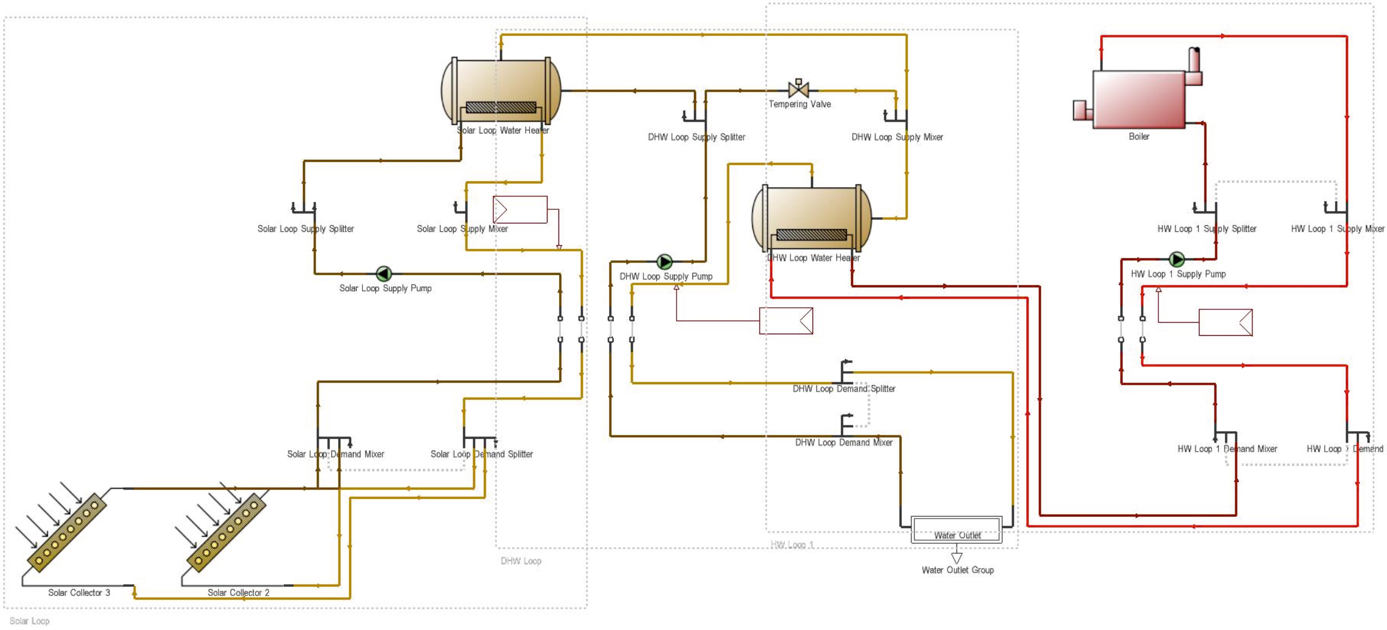

FIG. 4.5. Scheme of the solar domestic hot water system (Source: own elaboration)

Many climatic parameters influence the energy consumption of a building. Average monthly value of solar radiation intensity (Fig. 4.6, Fig. 4.7) and dry bulb temperature (Fig. 4.8) were selected for comparison. The highest intensity of direct solar radiation is in Cordoba. It is over four times higher than in Bialystok and almost two and a half times higher than in Bologna. In the case of diffuse radiation, it is the lowest in Cordoba in summer and the highest in winter. In other locations, the distribution of this radiation fraction is almost similar. Cordoba has by far the highest outside air temperature, especially in winter. The temperature in Bologna is slightly lower, while Bialystok, Kaunas, and Helsinki have a similar but significantly lower outside air temperature.

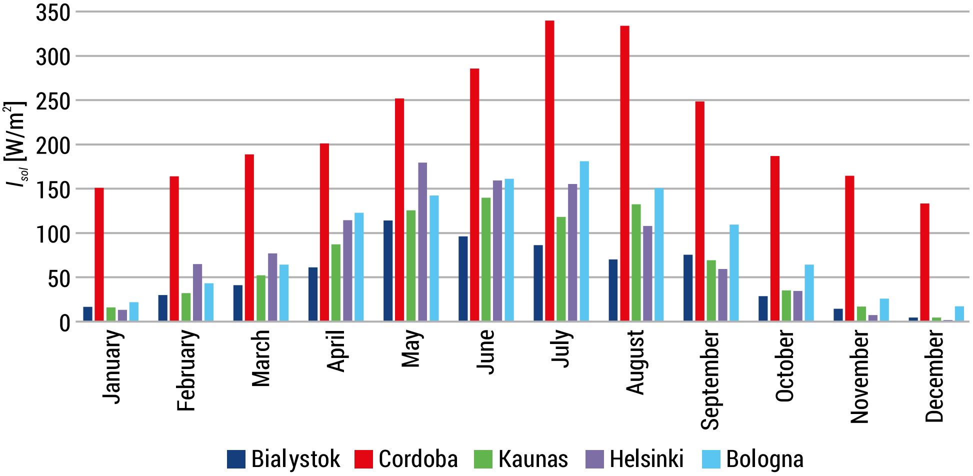

FIG. 4.6. Average monthly direct solar radiation rate per area [W/m^2] (Source: own elaboration)

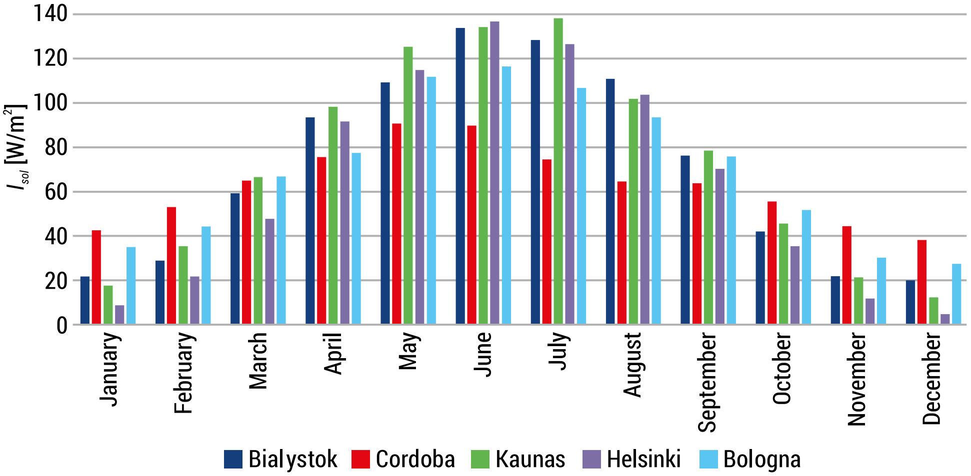

FIG. 4.7. Average monthly diffuse solar radiation rate per area [W/m^2] (Source: own elaboration)

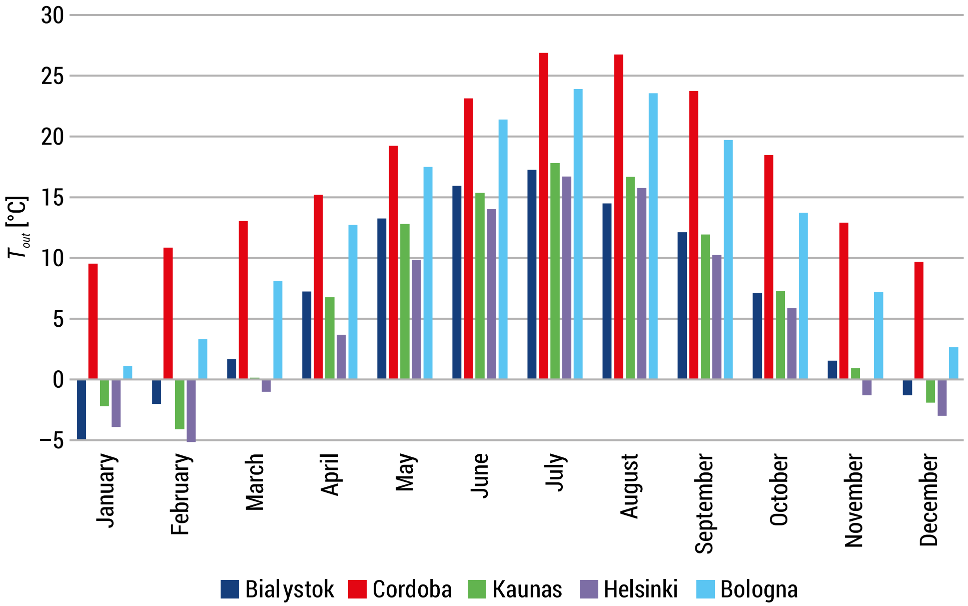

FIG. 4.8. Average monthly outdoor air dry-bulb temperature [°C] (Source: own elaboration)

4.2.3. Results of Simulations

Multivariate calculations were made over a period of one year for a typical meteorological year. First, the amount of energy needed to heat the building was determined. The simulation results for five locations are presented in Table 4.4. The E_F symbol denotes the final energy consumed by the building. It includes energy for heating, ventilation, DHW production and lighting. Total domestic primary energy demand, which is harvested directly from natural resources, has been marked as E_P. The Primary Energy Factor (*PEF*) was used to determine the E_P value and is defined as:

$$PEF = \frac{E_P}{E_F} \tag{4.1}$$

The value of coefficient *PEF* was assumed to be 2.5 for grid supplied electricity.

TABLE 4.4. Results of calculations of yearly energy demand (Source: own elaboration)

	Bialystok	**Kaunas**	**Helsinki**	**Bologna**	**Cordoba**
E_F [kWh]	7383.4	7249.0	7885.9	5803.4	4780.1
E_P [kWh]	18458.5	18122.4	19714.9	14508.4	11950.4

Obviously, the lowest energy consumption is in Cordoba. This is due to the highest values of the average temperature of the outside air and the intensity of solar radiation. Energy demand is around 20% higher in Bologna. However, in other locations, primary energy consumption is over 50% higher than in Cordoba.

Table 4.4 shows the R_{EF} and R_{EP} coefficients determining the energy consumption related to m^2 of space with controlled temperature:

$$E_{PF} = \frac{E_F}{A_{net}} \tag{4.2}$$

$$E_{PP} = \frac{E_P}{A_{net}} \tag{4.3}$$

The building's energy class was assessed on the basis of the Building Energy Rating (*BER*) value and is included in the last row of Table 4.5. The following primary energy consumption levels in kWh/m^2 were assumed for the building's energy category:

- $E_P < 25$ kWh/(m^2 year) – A1
- $E_P > 25$ kWh/(m^2 year) – A2
- $E_P > 50$ kWh/(m^2 year) – A3
- $E_P > 75$ kWh/(m^2 year) – B1
- $E_P > 100$ kWh/(m^2 year) – B2
- $E_P > 125$ kWh/(m^2 year) – B3
- $E_P > 150$ kWh/(m^2 year) – C1
- $E_P > 175$ kWh/(m^2 year) – C2
- $E_P > 200$ kWh/(m^2 year) – C3

TABLE 4.5. Yearly energy consumption per unit of conditioned area (Source: own elaboration)

	Bialystok	**Kaunas**	**Helsinki**	**Bologna**	**Cordoba**
E_{PF} [kWh/m^2]	41.60	40.85	44.44	32.70	26.93
E_{PP} [kWh/m^2]	104.01	102.12	111.09	81.75	67.34
Building Energy Rating (*BER*)	B2	B2	B2	B1	A3

The first three locations, i.e. Bialystok, Kaunas and Helsinki, have B2 in terms of energy consumption and a house with such characteristics cannot be classified as energy-efficient. The situation is slightly better in Bologna, and this type of building located in Cordoba already has a demand for non-renewable energy slightly below the upper limit of the energy-saving building.

The above results do not take into account the other energy sources using conversion of solar radiation technology. The next Table (4.6) compares the amount of energy produced by thermal solar collectors and photovoltaic cells.

TABLE 4.6. Yearly energy converted by solar collectors and photovoltaic cells (Source: own elaboration)

	Bialystok	**Kaunas**	**Helsinki**	**Bologna**	**Cordoba**
Thermal solar collectors [kWh]	1186.4	1318.9	1459.3	1466.8	2468.4
Photovoltaic cells [kWh]	3199.7	3680.3	3820.7	4084.4	6635.1

Based on the analysis of the results in Table 4.6, it can be seen that renewable energy systems are most efficient when they are located in Cordoba. The amount of energy obtained as a result of solar radiation conversion is almost double that of other locations.

Having considered renewable energy sources, a clear improvement in the level of primary energy consumption can be noticed (Table 4.7). This time, the buildings in Bialystok, Kaunas and Helsinki have BER at A2 level. The same building located in Bologna should be classified as passive, or actually almost zero-energy.

TABLE 4.7. Yearly energy consumption including renewable energy sources (Source: own elaboration)

	Bialystok	**Kaunas**	**Helsinki**	**Bologna**	**Cordoba**
E_{EF} [kWh]	2997.3	2249.8	2606.0	252.2	−4323.4
E_{EP} [kWh]	7493.3	5624.4	6514.9	630.5	< 0
R_{EP} [kWh/m^2]	42.22	31.69	36.71	3.55	< 0
Building Energy Rating (*BER*)	A2	A2	A2	A1	A1

This type of analysis should end with identifying those elements that have the greatest impact on the building's energy consumption. For this purpose, an exemplary percentage energy balance was prepared for a building located in Bialystok. As can be easily seen from the graph shown in Fig. 4.9, the biggest components of this balance are: energy consumption generated by electrical equipment, indoor lighting, and fans. Thus, in order to further reduce the level of energy consumption of this facility, it would be necessary to use computer and office equipment with a lower energy demand and to use more energy-efficient lighting that automatically controls its operation. A big source of savings can also be the replacement of the air handling unit with a more energy-efficient one or only the replacement of the fans and the use of control of their operation based on the concentration of carbon dioxide.

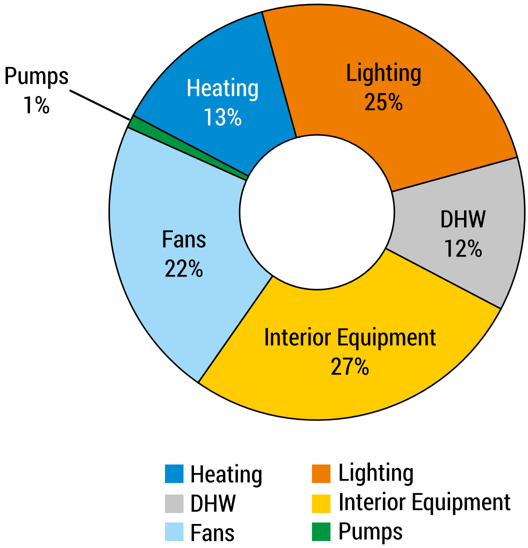

FIG. 4.9. Balance of final energy consumption (Source: own elaboration)

4.2.4. Summary of the Analysis and Conclusions

According to the regulations in force in the European Union, currently built houses must have a low demand for non-renewable energy. This chapter covers the analysis of a building with low energy consumption. The object of research was a laboratory building located at the Faculty of Architecture of Bialystok University of Technology. Its external partitions are characterized by a very high thermal resistance. Besides, a double skin facade was also designed to maximize heat gain from solar radiation. Various renewable energy systems were used in this building, such as: ground heat pump with vertical probes, thermal solar collectors and photovoltaic cells. The use of these types of technologies allowed for a significant reduction in the demand for primary energy compared to standard design solutions used in construction.

Currently, it is considered an energy-efficient house that consumes less than 70 kWh/(m^{2}year), low-energy from 15 to 30 kWh/(m^{2}year), passive from 0 to 15 kWh/(m^{2}year), and zero-energy that is the object does not consume primary energy. Based on the analysis, it should be concluded that the laboratory building meets the criteria of an energy-efficient house for three locations: Bialystok, Kaunas and Helsinki. It could be called passive in case we locate this building in Bologna. This house would produce more energy than it consumes, if built in the Cordoba area.

In the building, that is the object of this analysis, no air cooling devices are installed and only passive methods are used. Of course, in the summer this worsens the thermal comfort in towns such as Bologna and, above all, Cordoba. The use of air conditioning devices would significantly increase the demand for non-renewable energy. However, it should be noted that the excess energy produced by the photovoltaic system in Cordoba can be used to power air conditioning units during the summer. Thus, further energy analysis should take into account HVAC systems specif-ic for local needs.

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